

Diamond Light Source Proceedings

<http://journals.cambridge.org/DLS>

Additional services for *Diamond Light Source Proceedings*:

Email alerts: [Click here](#)

Subscriptions: [Click here](#)

Commercial reprints: [Click here](#)

Terms of use : [Click here](#)

Design and Fabrication of Magnet Coils

M. Jaski

Diamond Light Source Proceedings / Volume 1 / Issue MEDSI-6 / October 2011 / e7

DOI: 10.1017/S2044820110000158, Published online: 08 October 2010

Link to this article: http://journals.cambridge.org/abstract_S2044820110000158

How to cite this article:

M. Jaski (2011). Design and Fabrication of Magnet Coils. Diamond Light Source Proceedings, 1, e7 doi:10.1017/S2044820110000158

Request Permissions : [Click here](#)

Poster paper

Design and Fabrication of Magnet Coils

M. J A S K I †

Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

(Received 11 June 2010; accepted 2 September 2010)

Users at the Advanced Photon Source (APS) requested a special purpose undulator that required 456 electromagnetic coils. This paper discusses the design and fabrication techniques used at the APS to build these room-temperature coils. The coils are made from insulated square copper conductor and are vacuum impregnated with epoxy.

1. Coil design

The coils are designed to place as much copper as possible in the available volume. The packing factor for this coil ranges between 65.8 and 76.4 % depending on where the conductor size falls within its tolerance range.

The square conductor is C110 copper insulated with double polyester glass over heavy polyamide-imide enamel. The conductor is supplied with an outer-dimensional tolerance. The smallest possible conductor area is used to calculate the coil resistance, giving a conservative heat-load estimate. The largest possible conductor area is used to determine the largest possible overall size of the coil. Allowances for key-stoning (Tanabe 2005), twisting, fibreglass thickness and Kapton tape thickness are included to determine the overall size of the coil.

Figure 1 shows the cross-section layout of the coil geometry. The coil consists of a 4×12 array of a square conductor. Spaces are needed for the conductor cross-overs so there are only 46 turns per coil (not $4 \times 12 = 48$). Figure 2 shows a model of the coil winding with spaces that are filled with plastic inserts made by a 3-D printer.

2. Winding

Winding is done using a split mandrel with a tapered seam along with end collars to properly size the coil. Figure 2 shows a model of the winding fixture. The winding fixture is made of steel.

Before winding, all parts of the winding fixture are cleaned and coated with the epoxy supplier's recommended mould release. Rubber surgical gloves are used to avoid contaminating the conductor with human body oils that can prevent the epoxy from sticking. The winding fixture is clamped to a winder or lathe. The

† Email address for correspondence: jaski@aps.anl.gov

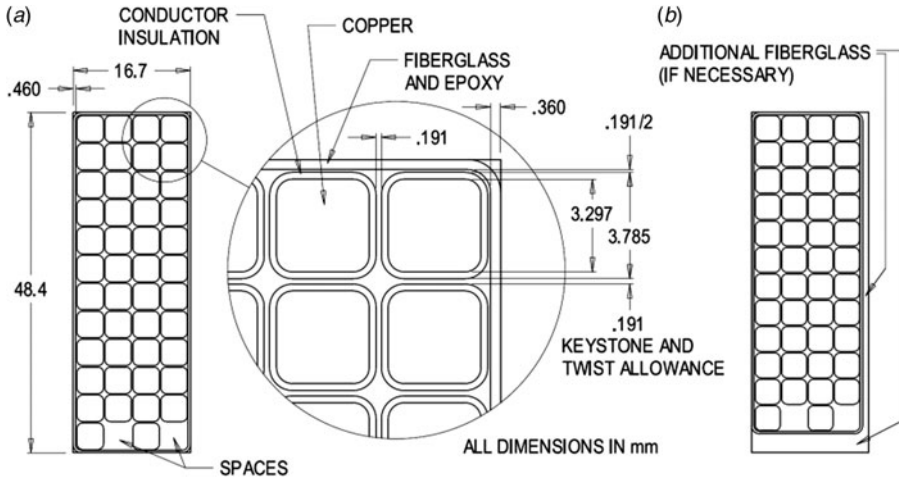


FIGURE 1. Layout of conductor geometry: (a) maximum size conductor, (b) minimum size conductor.

spool of conductor is mounted on an unwinding device with an adjustable air brake.

The end lead is clamped to the main collar, and the first coil layer is wound on the winding fixture. A thin layer of oven-cure epoxy is applied to the first coil layer with a paint brush. Table 1 lists the epoxy formula. The epoxy formula is mixed in a beaker and stirred by hand with a stirring stick.

A plastic insert is placed into position and winding of the next layer is started. This procedure is repeated until the coil winding is complete.

The coil and winding fixture are placed in an oven with the lead end at the lowest point allowing excess epoxy to run and build up, creating a stronger joint where the leads come out of the coil. The epoxy is cured using the curing cycle outlined in table 2. The coil is removed from the winding fixture and prepared for vacuum impregnation. The winding fixture is cleaned and reused.

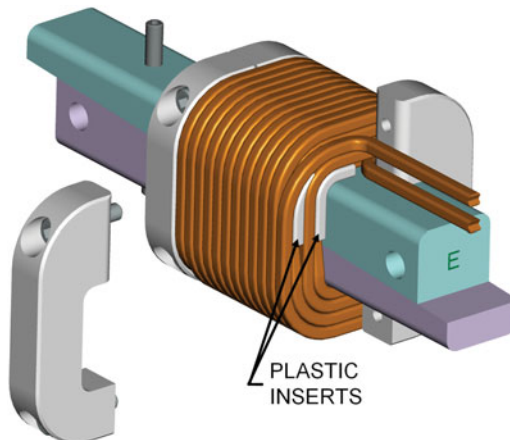


FIGURE 2. Model of the coil winding fixture.

Description	Parts by weight
828 epoxy resin	75
Nadicmethylanhydride (NMA)	90
Benzyltrimethylamine (BDMA)	1
Heloxy TM 505 (Hexion Specialty Chemicals, Inc.)	25

TABLE 1. Heat-cure epoxy formula.

3. Potting

The coil is wrapped with two layers of 178- μm -thick fibreglass tape along only the straight sides and secured with two pieces of 50- μm -thick Kapton tape on the inside of the coil (see the coil in figure 3). The coil is not wrapped with fibreglass tape around the corners because this creates a build up that can compromise the coil fit in the potting mould. If the delivered conductor is small and there is room, a belly-band wrap of fibreglass can be added to the outside of the coil (figure 1*b*). Fibreglass is added to the bottom of the coil (figure 1*b*) to minimize the epoxy thickness at the top of the coil.

The potting mould assembly is shown in figure 3. The potting mould is made of steel. Mould release is applied to the potting mould. The fibreglass-wrapped coil is assembled in the potting mould. A neoprene rubber round cord gasket is used to seal the chamber halves. An electrical high-pot test is done to check for an electrical short between the coil and the potting mould. Electrical shorts are repaired before potting continues. The top cover, epoxy dam and centre post clamp are removed from the assembly. The epoxy filling will be done without these items to avoid air bubbles forming at the top of the coil in the epoxy.

The potting mould and the individual epoxy ingredients are preheated to 55°C. The epoxy ingredients are placed in a vacuum chamber and outgassed (air is removed) until there are no more bubbles. All outgassing is done using less than a 2 mTorr vacuum.

A schematic of a vacuum impregnation system along with several excellent coil fabrication techniques is given by (Tanabe 2005). The potting mould assembly is placed in the vacuum chamber, and the epoxy fill hose is attached to the epoxy fill tube. The potting epoxy formula (table 1) is mixed while the ingredients are warm. The epoxy mixture is outgassed and carefully poured into the fill tank so as not to create air bubbles. A vacuum less than 2 mTorr is applied to the potting mould vacuum chamber. The valve for the epoxy fill is slowly opened, allowing epoxy to slowly fill the potting chamber. The chamber is full when the coil is fully covered in the epoxy. A flow channel is provided on the potting chamber to guide overflowing epoxy to drain off to the side of the mould. The epoxy valve

Gel at 88°C for 4 h
 Cure at 150°C for 6 h
 Cool to 55°C

TABLE 2. Heat-cure cycle for epoxy.

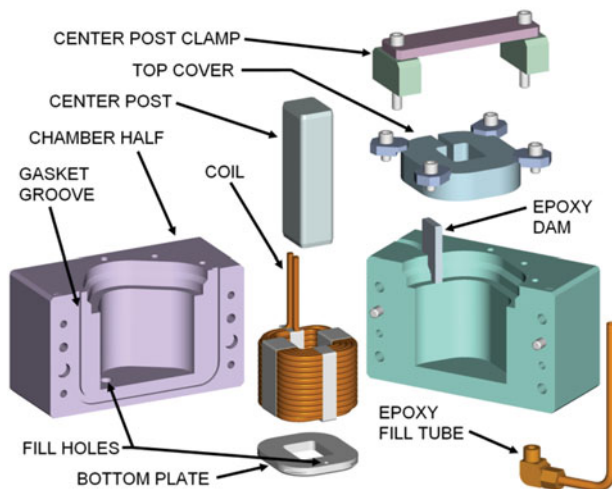


FIGURE 3. Potting mould assembly.

is closed, and the epoxy in the mould is allowed to outgas and settle. It is best to allow 30 min or longer for this step. More epoxy can be added by opening the fill valve if necessary.

Once the epoxy has settled and no more outgassing bubbles are seen, the potting mould is removed from the vacuum chamber. The preheated top cover, epoxy dam and center post clamp are installed on the potting mould assembly. The potting mould assembly is placed in an oven where the epoxy is cured using the curing cycle listed in table 2. The coil is removed from the potting mould. The centre post is Teflon coated and can be pushed out of the coil using a small hand press. Excess epoxy flashing is removed from the coil and the coil is taken for electrical testing. The epoxy fill tube is discarded and replaced with a new one. The potting mould is cleaned and reused.

Our work is supported by the US Department of Energy, Office of Science, Office of Basic Energy Sciences under contract number DE-AC02-06CH11357.

REFERENCES

- Hexion Specialty Chemicals, Inc., Houston, TX. <http://www.hexion.com/Products/TechnicalData/Sheet.aspx?id=2635&terms=hexion+505>.
- TANABE, J. T. 2005 Iron Dominated Electromagnets, 1st edn. pp. 267–284, World Scientific Publishing Co. Pte Ltd.